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A path to low-emission, on-demand, large-scale power generation and propulsion: Progress and challenges in carbon-free firing of gas turbines and the role of combustion research

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Abstract: Efforts to curb emissions of greenhouse gases and atmospheric pollutants while meeting the stability requirements of modern energy systems at the needed scale will involve the use of low-carbon or carbon-free chemical energy carriers – e.g. syngas, methane, methanol, ammonia, hydrogen and their blends. The steady, constant-pressure combustion processes that characterize Brayton thermodynamic cycles have the best potential to handle fuels with very different heating value and seamlessly switch between fuel-oxidant mixtures of varying reactivity. Therefore, based on fundamental cycle characteristics and following opportune adaptations of their combustion system, modern gas turbines are intrinsically well-suited to satisfy future requirements for fuel flexibility while still ensuring fast-response, on-demand, large-scale power generation at high cycle efficiency with low-emissions. In this context, the development of advanced dry low emission (DLE) premixed combustion systems is a key enabling step and is proceeding principally along three directions of research, each providing more robust flame stabilization while minimizing undesired emissions: 1) advanced piloting strategies that improve upon "traditional" aerodynamic flame stabilization and propagation; 2) novel injection systems that implement a spatially-distributed fuel delivery and heat release process; and 3) hybrid flame stabilization strategies based on longitudinal/sequential fuel staging and reheat combustion systems controlled by spontaneous ignition. The performance of these alternative approaches to combustion systems design and their impact on the gas turbine operability remain to be comparatively assessed for a wide range of fuels. Therefore, numerical modeling of turbulent reactive flows will continue to play a crucial role in supporting the gas turbine industry and reducing the development cost of clean and efficient power generation and propulsion.

Bio: Andrea Gruber holds a doctoral degree in Mechanical Engineering from NTNU (2006), he is Senior Research Scientist at SINTEF Energy Research and Adjunct Professor at NTNU. His research interests are in the development and application of massively parallel direct numerical simulations (DNS), a first-principle, high-fidelity numerical modelling approach, to achieve detailed insight and obtain accurate predictions of turbulent reactive flows. Dr. Gruber has performed DNS on some of the research challenges related to combustion of highly-reactive and non-standard fuels in gas turbines (hydrogen in particular). Pursuing industrial relevance within the framework of numerous national and international research initiatives (BIGH2, NCCS, DiHI-Tech, ENCAP, DECARBit) and in close partnership with the gas turbine industry (ALSTOM, Ansaldo Energia, Siemens Energy), he has contributed to the fundamental understanding of key turbulence-chemistry interaction processes that play a major role in the achievement of clean and efficient power generation: design and optimization of fuel injection systems, flashback prediction and control, static and dynamic flame stabilization in conventional and staged combustion systems.